Tanta University
Faculty of engineering
Electrical Power and Machines engineering department
Energy Conversion Course

Sheet (5) …… Synchronous Machines

1) A 3-ϕ, Y-connected, wound rotor synchronous generator rated at 10 KVA, 230 V, 60 Hz has the following parameters, Xs = 2 Ω / phase and Rs = 0.5 Ω /per phase. The generator is connected to infinite bus. Calculate the percent voltage regulation at full load with 0.8 lagging power factor, 0.6 leading power factor and unity power factor.

2) A 230 V, 3-ϕ, Y-connected wound rotor synchronous generator gives on open circuit, e.m.f of 230 V, for afield current of 0.38 A. The same field current on short circuit causes an armature current of 12.5 A. The armature resistance measured between two lines is 1.8 Ω. Find the regulation for the current of 10 A at 0.8 lagging and 0.8 leading power factors.

3) A 230 V, 3-ϕ, Y-connected wound rotor synchronous motor has Xs = 3 Ω/ phase and Rs = 0.25 Ω/phase. The motor operates on load such that the power angle is **-15°**, and the excitation is so adjusted that the internally induced voltage is equal in magnitude to the terminal voltage. Determine:
a) The armature current.
b) The power factor of the motor.

Best wishes
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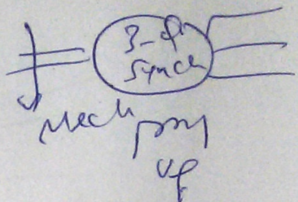
$Z = R + jX$

Sheet 5

① Req: VR%.



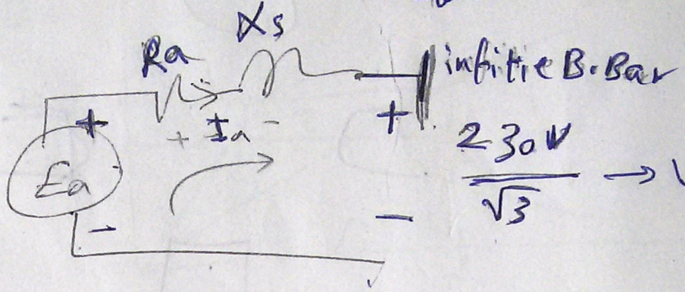
$10\,kVA = S$

$V_L = 230V$

$f = 60\,Hz$

$X_s = 2\,\Omega$

$R_a = 0.5\,\Omega$



$\frac{230V}{\sqrt{3}} \rightarrow V_{ph}$

a) $Pf = 0.8$ lag

$$I_a = \frac{S}{\sqrt{3} V_L} = \frac{10 \times 10^3}{\sqrt{3} \times 230} = 25.102 \angle -36.87 \, A$$

$$V_{ph} = \frac{230}{\sqrt{3}} \angle 0 = 132.79 \angle 0$$

$$\underset{E_{f.L}}{E_a} = \underset{E_{f.L}}{V_{ph}} + \underset{E_{n.L}}{I_a (R_a + jX_s)} = |\,| \angle +\delta = 176 \angle \underset{\delta}{10.68} \, V$$

$$\% VR = \frac{E_a - V_{ph}}{V_{ph}}_{E_{n.L}} \times 100 = \boxed{32.53\%}$$

+ve → for lag P.f

for lead P.f $= 0.6$

$\therefore I_a = 25.102 \angle \cos^{-1}(0.6) = 25.102 \angle 53.13 \, A$

$\therefore \underset{E.L}{E_a} = 107.91 \angle 21.85 \, V$

$\therefore \% VR_{ge} = \frac{107.91 - 132.79}{132.79} \times 100 = -18.73\% \longrightarrow$ −ve for lead P.f

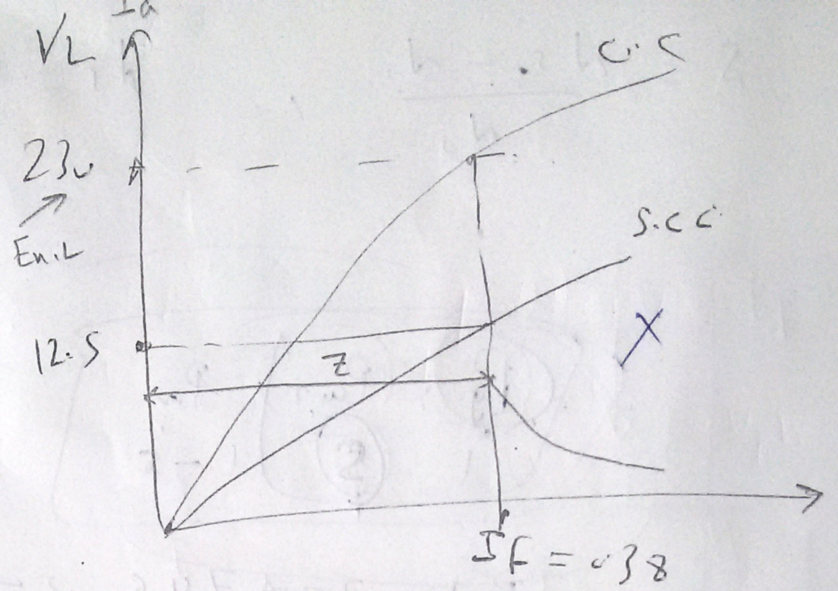
for unity $\quad I_a = 25.102 \angle 0 \quad \therefore \underset{f.L}{E_a} = 135.142 \angle 10.7 \, V$

$\therefore \% VR_g = \frac{135.142 - 132.79}{132.79} \times 100 = 1.77\%$

② Req VR%.

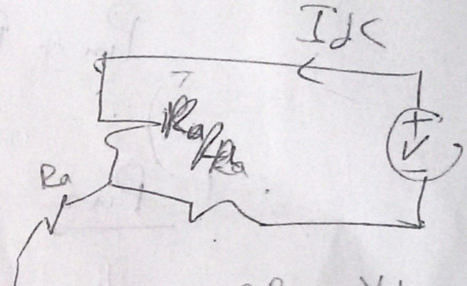
$V_{ph_{En.L}} = \dfrac{230}{\sqrt{3}}$

$I_f = 0.37A$



$I_{sc} = 12.5\,A$

$Z_s = \dfrac{230/\sqrt{3}}{12.5} = 10.6232\,\Omega$



$R_{a_{dc}} = \dfrac{1.8}{2} = 0.9\,\Omega$

$\dfrac{V_{dc}}{I_{dc}} = 2R_a$

$2R_a = \dfrac{V_{dc}}{I_{dc}} = 1.8$

$\therefore R_{a_{d.c}} = \dfrac{1.8}{2} = 0.9$

$R_{a_{a.c}} = 0.9 \times 1.25$

$R_a = 0.9 \times 1.25 = 1.125\,\Omega$

$X_s = \sqrt{Z_s^2 - R_a^2} = 10.5634\,\Omega$

$I_a = 10\,A$

$E_a = V_{ph} + I_a(R_a + jX_s) = \angle\delta$

at 0.8 lag P.F. $\therefore I_a = 10\angle -\cos^{-1}(0.8) = 10\angle -36.87\ A$

$\therefore E_{af.L} = 219.411\angle 20.72\ V$

$\%\,VReg = \dfrac{E_{f.L} - E_{n.L}}{E_{n.L}} \times 100 = \dfrac{219.411 - 132.79}{132.79} \times 100 = 65.23\,\%$

at 0.8 lead P.f $\therefore I_a = 10\angle 36.87\ A$

$\therefore E_{af.L} = 120.316\angle 49.33\ v$

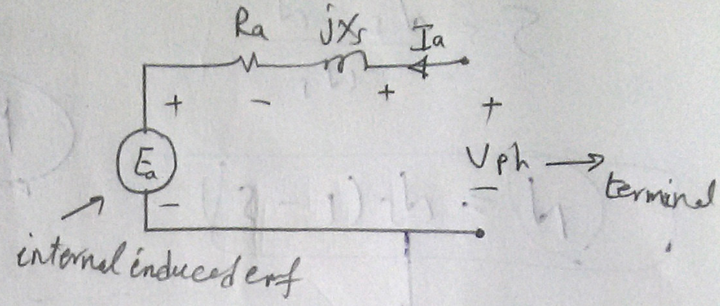
$\therefore \%\,VR = \dfrac{120.316 - 132.79}{132.79} \times 100 = -9.4\,\%$

(3) $V_L = 230\,V$

$X_s = 3\,\Omega$

$R_a = 0.25\,\Omega$

$\boxed{\delta = -15^\circ}$



$V_{ph} = V_t = I_a(R_a + jX_s) + E_a$

$\therefore I_a = \dfrac{V_t - E_a}{R_a + jX_s}$

$V_t = \dfrac{230}{\sqrt{3}} \angle 0\ V$

$E_a = \dfrac{230}{\sqrt{3}} \angle -15^\circ\ V$

$\therefore I_a =$

$|E_a| = |V_{ph}|$

$V_{ph} = \dfrac{230}{\sqrt{3}} = \checkmark \angle 0$

$E_a = \dfrac{230}{\sqrt{3}} \angle -15$

$E_a = V_{ph} - I_a(R_a + jX_s)$

$I_a = \dfrac{V_{ph} - E_a}{R + jX_s} = \; \angle$

$11.515 \angle -2.736$

$P.f. = \cos(\hat{V}_{ph} - \hat{I}_a) = \cos(0 + 2.736)$

$\boxed{= 0.9988 \text{ lag}}$

sheet 5

1. 8 Pole , 3-ph Synch. Gen. Y-Conn.
168 slots with 9 Cond./slot. $N_r = 750$ rpm, $K_w = 0.96$
E.m.f = 1000 V between lines.
Req: $\phi = ?!$

Solution

$$E_{ph} = 4.44 * \phi * f * T_{ph} * K_w$$

where $T_{ph} \longrightarrow$ no. of turns per phase

$$Z = 168 * 9 = 1512 \text{ Conductors}$$

$$\text{no. of turns} = \frac{Z}{2} = 756 \text{ turns}$$

$$\therefore T_{ph} = \frac{756}{3} = 252 \text{ turns}$$

$$\because N_s = \frac{120 f}{P} \quad \therefore f = \frac{N_s * P}{120} = \frac{750 * 8}{120} = 50 \text{ Hz}$$

N_s $\hookrightarrow$ = N_r for synch. machines

$$E_{ph} = \frac{1000}{\sqrt{3}} = 577.35 \text{ V}$$

$$\therefore \phi = \frac{E_{ph}}{4.44 * f * T_{ph} * K_w}$$

$$\therefore \phi = \frac{577.35}{4.44 * 50 * 252 * 0.96} = 10.75 \text{ mWb}$$

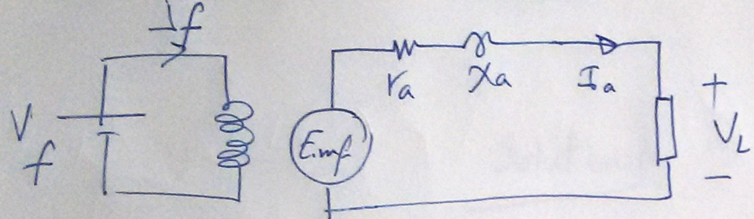
(2) $S_{rated} = 50\,KVA$, Y-Conn. $V_L = 440\,V$, $f = 50\,Hz$, $r_a = 0{,}25/ph$

$X_a = 3.7\,\Omega/ph$

→ for unity P.f. & rated load:

(1) $E.m.f_{ph}$ (2) VR%. (3) sketch phasor diagram

Solution



$S = \sqrt{3} V_L I$

$= 3 V_{ph} I$

$$E.m.f_{ph} = V_{Lph} + I_a(r_a + jX_a)$$

assume the load voltage is the Ref.

$$\therefore V_{Lph} = \frac{440}{\sqrt{3}} \angle 0 = 254 \angle 0^\circ \ V$$

$$I_a = \frac{S_{rated}}{\sqrt{3} * 440} = 65.607 \angle 0^\circ \ A \quad \text{(unity P.f.)}$$

$$\therefore Emf_{ph} = 254 \angle 0^\circ + 65.607 \angle 0^\circ (0{,}25 + j\,3.7)$$

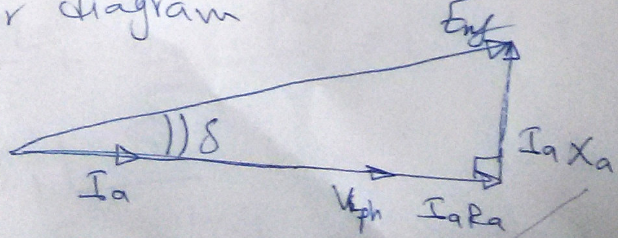
$$\therefore Emf_{ph} = 363{,}38 \angle 42^\circ \ V$$

42° → δ load angle

$$\%VR = \frac{Emf_{f.L} - Em_{n.L}}{Em_{n.L}} * 100 = \frac{363.38 - 254}{254} * 100$$

$\%VR = 43\%$

phasor diagram



(3) 3ph gen. $P_{rated} = 5KW \longrightarrow P_{out}$ $V_L = 110$ V, 29A lag P.f.

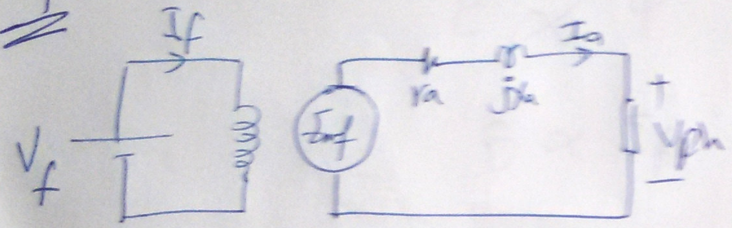
$f = 50$ HZ, 1000 rpm, $r_a = 0.1\ \Omega/ph$, $X_a = 1.53\ \Omega/ph$

- I_{f_1} (Full load Current)

Req.: (1) $Emf_{n.L}$, %VR, Poles no.

Solution

a)



Alternator

ssynch generator

at no-load

$Emf_{n.L} = V_L/\sqrt{3} = \frac{110}{\sqrt{3}}$ V

$N_s = \frac{120f}{P}$ ∴ $P = \frac{120f}{N_s} = \frac{120 * 50}{1000} = 6$ poles

$P = 3 V_{ph} I_{ph} * Pf$

$5 * 10^3 = 3 * \frac{110}{\sqrt{3}} * 29 * pf$

$\phi = ✓$

$\cos\phi = pf = ✓$

$E = V + I_a(r_a + jX_s)$

$= \frac{110 \angle 0}{\sqrt{3}} + 29 \angle{-\phi} * (0.1 + j1.53)$

$E = | \ | \angle \delta$

$V_{reg}\% = \frac{E - 110/\sqrt{3}}{110/\sqrt{3}} * 100 =$

b)

$$I_{f_2} = 0.9\, I_{f_1}$$

$$N_2 = N_1$$

$$E = 4.44\, f\, \phi\, K_w\, T_{ph}$$

$$E \propto f\, \phi$$

$$E \propto \phi$$

$$\phi \propto I_f$$

$$E_2 = 0.9\, E_1 =$$

نفس

$$E_2 \angle \delta = V_2 + I_a\,(r_a + jX_s)$$

نفس التيار والزاوية

$$V_2 = \quad ?? \angle$$

c) $pf_3 = 0.8$ lead

$$I = 29 \angle +\cos^{-1} 0.8$$

تكرر المطلوب a (A) مع حساب قيمة V الجديدة

و E_1 ثابتة

$$E_3 = E_1$$